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D. M. Worrall and R. C. Lamb

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X-RAY EMISSION FROM THE REGION OF γ195+5

R. C. Lamb*

Department of Physics, Iowa State University

D. M. Worrall**

NASA/Goddard Space Flight Center

ABSTRACT

X-ray emission from the vicinity of the > 100 MeV γ-ray source, γ195+5, has been observed with the HEAO-A2† detectors. A source with an intensity of $(1.5 \pm 0.5) \times 10^{-11}$ erg cm^{-2} s^{-1} (2-6 keV) was seen in each of two separate observations at a combined confidence level of 3.1 σ. The location of the source is: $\ell^{II} = 194.^{\circ}56$, $b^{II} = 4.^{\circ}92$ with a 90% confidence error box of 1.4 square degrees, significantly smaller than the positional uncertainty of the γ-ray source, and consistent with its location. The chance overlap of such an X-ray source with the γ-ray region is estimated to be 9% and therefore they may be associated. The photon number spectrum may be fitted either with a power law with an exponent of $2.6 \begin{smallmatrix} +0.7 \\ -0.6 \end{smallmatrix}$ and absorption column density $< 7 \times 10^{22}$ H atoms cm^{-2} or by thermal bremsstrahlung emission with $kT = 6 \pm 3$ keV and absorption $< 4 \times 10^{22}$ H atoms cm^{-2}. The spectrum appears too steep to extrapolate simply to the 100 MeV flux value for γ195+5.

* HEAO-1 Guest Investigator

**Also Dept. of Physics and Astronomy, Univ. of Maryland

†The HEAO-A2 experiment is a collaborative effort led by E. Boldt of GSFC and G. Garmire of CIT, with collaborators at GSFC, CIT, JPL, and UCB.

I. INTRODUCTION

The recent discoveries by the COS-B satellite (Hermsen et al. 1977, Pinkau 1979) combined with earlier SAS-2 observations (Kniffen et al. 1977) bring the number of localized regions of γ-ray emission for energies above 100 MeV to more than 25. The intensity of these sources ranges from 12×10^{-6} (photons > 100 MeV) $cm^{-2}s^{-1}$ for the Vela Pulsar (Thompson et al. 1977b) to ~ 1×10^{-6} (photons > 100 MeV)$cm^{-2}s^{-1}$ for the weaker sources. In addition to Vela, identifications with known celestial objects have been made for the Crab Pulsar (Kniffen et al. 1974), Cygnus X-3 (Lamb et al. 1977), 3C273 (Swanenburg et al. 1978), and four radio pulsars (Ögelman et al., 1976, Thompson et al. 1976, and Buccheri, et al. 1978). However more than 2/3 of these sources await identification at other wavelengths. One of the brightest of the unidentified sources is located in the direction of the galactic anticenter and is referenced by its galactic coordinates as γ195+5 (Thompson et al. 1977a) or CG195+4 (Hermsen et al. 1977).

In this paper we describe observations of this region of the sky which sought to establish the level of X-ray emission from γ195+5. The motivation for this work follows from a general interest in identifying any one of the γ-ray sources at other wavelengths, the theoretical interest already evident for this particular source, and the fact that the source is located in the galactic anticenter where the density of known background X-ray sources is low. A previous search of this region for X-ray emission with Uhuru data has been reported by Julien and Helmken (1978).

The γ-ray intensity of γ195+5 is $4.3 \pm 0.9 \times 10^{-6}$(photons > 100 MeV) cm^{-2}-s^{-1}, comparable to that of the Crab, and its spectrum is somewhat harder. Thompson et al. (1977a) place a limit on the spectral number index

($dN/dE \propto E^{-\alpha}$) with α less than 1.9 at the 95% confidence level. An apparent 59 sec periodicity was reported by the SAS-2 group (Thompson et al. 1977a) and an early confirmation by COS-B (Masnou et al. 1977) stimulated theoretical work based on this feature. Maraschi and Treves (1977) have made several proposals and favor a model in which the periodicity is the precession period of a rapidly rotating neutron star. Davies, Fabian and Pringle (1978) have identified the period as a rotational period of a neutron star which is slowing at the rate indicated by the observations. Energetics led them to the conclusion that the neutron star may be the companion of the nearby star γ Geminorum, 30 pc away. A different viewpoint has been expressed by Abdulwahab and Morrison (1978) who propose a model to account for all of the anticenter sources as the result of the interaction of a burst of cosmic rays from the Crab supernova event and interstellar clouds.

The X-ray observations described in this paper were carried out with the A2 experiment detectors (Rothschild et al. 1978) of the HEAO-1 satellite. A weak source was found in each of two separate observations at a combined confidence level of ~ 3σ that the effect is not spurious. The energy flux of the source is $(1.5 \pm 0.5) \times 10^{-11}$ erg cm^{-2}s^{-1}(2-6 KeV) and arguments are presented in the paper which indicate that the chance overlap of such a source with the γ-ray error boxes is about 9%. The 90% confidence error box of the HEAO-1 source has an area of 1.4 square degrees and will guide further identification work with the HEAO-2 imaging X-ray satellite.

II. OBSERVATIONS AND RESULTS

The A2 detectors of the HEAO-1 satellite have been described in detail by Rothschild et al. (1978). They consist of 6 gas-filled multi-layer, multi-wire proportional counters which are mechanically collimated with

different fields-of-view ranging from $3^\circ \times 6^\circ$ to $3^\circ \times 1\ 1/2^\circ$. For a point source the detectors with the smallest field of view ($3^\circ \times 1\ 1/2^\circ$) have the best signal/background ratio and therefore were found to be the most sensitive for searching for possible sources. In the scanning mode of HEAO-1 the detectors cover a great circle band on the sky 3° wide every 1/2 hour with the rotation axis pointed toward the sun. The source region of interest is near the ecliptic equator and therefore appears in the field of view for ~6 days every 6 months. Data for this paper were taken from two periods of time 29 September - 4 October 1977 and 26 - 31 March, 1978. In addition a 6 hour pointed observation was carried out on 6 April, 1978. In both the October 1977 and the March 1978 data two sources were observed within a region of approximately 50 square degrees (10° in scan angle by 5° in the orthogonal direction) centered on the γ-ray source region. One of the sources may be identified with the previously catalogued 4U0617+23 (IC443) (Forman et al. 1978), ~6° from the γ-ray source. The other source is apparently new and its statistical significance is now discussed.

The technique of summing the A2 scan data to search for suspected sources is described by Marshall et al. (1979). For both sets of scanning data, a strip ~10° in scan angle centered on the γ-ray source region was fitted by a constant background plus the known source (IC443). For each data set the χ^2 of the fit was reduced when an additional source was added. For the October set of observations the scan angle position of the added source was a free parameter which was allowed to vary anywhere along the 10° strip. With this freedom the maximum reduction in χ^2 was 9 units. The statistical significance of this reduction may be estimated by the f-test method (cf. Bevington, 1969) which indicates that the confidence

level that the result is a statistical fluctuation is 0.008. The narrow field-of-view A2 detectors can resolve sources separated by $\gtrsim 1^{\circ}$ in scan angle so that, in the immediate vicinity of the γ-ray error boxes, there are approximately 5 resolvable positions. Thus the probability that the effect is a fluctuation should be increased to 5x0.008 = 0.04.

For the second series of observations six months later the data also indicated the presence of a new source. When the scan angle of the source added to this data set was allowed to vary, the maximum reduction in χ^2 was five units. When the scan angle was fixed at the value determined from the first observation the same reduction in χ^2 occurred, that is, the identical scan angle is essentially the best fit scan angle, the difference being only $0\overset{\circ}{.}02 \pm 0.38$. The probability that the effect from the second data set alone is a fluctuation is 0.05. Since the positions are in agreement we have combined the probabilities to reach an overall significance level of (0.04)(0.05) = 0.002, equivalent to a 3.1σ result. In both data sets no other new source was indicated anywhere within a region of approximately 50 square degrees.

Normally a 3σ result would not be considered strong evidence to claim a new X-ray source. Certainly this would be true if this were a random position in the sky. However this source does represent the region of strongest possible X-ray emission near the γ-ray position and therefore it may be significant. A best position of the X-ray source may be derived for each observation. As indicated above, the difference in scan angle for the two positions is $0\overset{\circ}{.}02 \pm 0.38$; the difference in the angle perpendicular to the scan direction is $0\overset{\circ}{.}65 \pm 0.61$. The combined 90% confidence error box for the source is shown in figure 1, along with the 47% confidence error box of SAS-2 (Thompson et al. 1977a) and the COS-B error box (Hermsen et al. 1977). Although the

significance of the COS-B error box has not been stated, one may infer from the quoted COS-B positions of known objects (the Vela and Crab pulsars) that its significance is comparable to the SAS-2 result. Therefore, we claim that the position of the X-ray source is consistent with both γ-ray error boxes. The best position of the source is $\ell^{II} = 194\overset{\circ}{.}56$, $b^{II} = 4\overset{\circ}{.}92$. The corners of the error box are given approximately by $\alpha = 97\overset{\circ}{.}3$ to $98\overset{\circ}{.}8$, $\delta = 18\overset{\circ}{.}1$ to $19\overset{\circ}{.}1$.

The error in deriving the intensity of such a weak source is dominated by intrinsic fluctuations in the diffuse sky component which is about 5% of the average for the A2 detectors. For a source spectrum different from that of the diffuse background, spectral parameters are also affected. For establishing the spectrum, the data of the pointed maneuver are used and the background taken from source-free accumulations at high galactic latitude. When this background is subtracted from the Xenon data of the pointed observation, an excess occurs, the intensity of which is consistent within background fluctuation errors with the source's intensity as determined from the scan data. The source is the only known source within the field of view during the pointing and therefore we ascribe this excess to the source. The possible contribution from the diffuse galactic X-ray emission (cf. Weaton 1976) is calculated to be not more than 10% of the point source signal.

In figure 2 the energy flux density, E dN/dE, of the source is shown. The photon number spectrum may be fitted either with a power law $dN/dE \propto E^{-\alpha}$ with $\alpha = 2.6^{+0.7}_{-0.6}$ and absorption column density $< 7 \times 10^{22}$ H atoms cm^{-2} or by thermal bremsstrahlung emission with $kT = 6 \pm 3$ keV and absorption $< 4 \times 10^{22}$ H atoms cm^{-2}. The errors and upper limits on spectral parameters are formal 2σ values, however they more realistically represent 1σ estimates after the

fluctuation uncertainty in the diffuse background level has been taken into account. The energy flux integrated from 2 to 10 keV is $(2.1\pm0.7) \times 10^{-11}$ ergs $cm^{-2}s^{-1}$; the 2 - 6 keV flux is $(1.5\pm0.5) \times 10^{-11}$ ergs $cm^{-2}s^{-1}$ or approximately 0.9 Uhuru counts s^{-1}. The cross-hatched region indicates a range of permissible spectra consistent with these errors, in that the 2-10 keV flux under the upper curve is 2.8×10^{-11} ergs $cm^{-2}s^{-1}$; the flux under the lower curve is 1.4×10^{-11} ergs $cm^{-2}s^{-1}$. However the reader is cautioned that some spectra which lie inside the cross-hatched region are unlikely by virtue of the error limits on the absorption, the power law exponent, or the temperature. Also shown in figure 2 is an estimate of the γ-ray energy flux assuming a number spectral index, α, in the vicinity of 100 MeV of 1.5.

The $\sim 10^4$ seconds of data of the pointed observation have been analyzed to determine if there are any significant frequency components present. None was seen. Unfortunately, because of the small signal-to-background, this result is not significant in that even if the source were 100% pulsed at a single frequency the Fourier amplitude of that component would have a magnitude comparable to 2-3σ fluctuations from random processes.

III. DISCUSSION AND CONCLUSIONS

We may calculate the probability of seeing any X-ray source within the ~10 square degrees of the γ-ray error boxes from published values of the number versus intensity relation. The extragalactic component source density is given by: $n(>S)=kS^{-3/2}$ sources sr^{-1} with $k=15\pm3$ and S in Uhuru counts/s (Warick and Pye 1978). The galactic component scales as $S^{-0.4}$ (see, for example, Forman et al. 1978, Matilsky et al. 1973) being 1.2 times the extragalactic density when they are extrapolated to 1 Uhuru count/s. From the 4U catalog (Forman et al. 1978) the number of low latitude sources, $|b|<10^\circ$, in the region

of the anticenter (ℓ = 120° to 240°) is 0.61 that expected from a distribution which is uniform in longitude. Therefore we have taken the galactic source density in the region of the anticenter to be given by: $n(>S) = kS^{-0.4}$ with k = (1.2)(0.61)(15) = 11. Using the sum of the two distributions, we calculate the probability of seeing a source with an intensity of 0.9 Uhuru counts/s or greater within the γ-ray region to be 9% on the basis of chance alone. Thus the observation of such a source is indicative that it may well be associated with the γ-ray source and is not a random coincidence.

An X-ray source, observed by the Uhuru satellite at the 2.7σ level of significance within the COS-B error box, has previously been discussed by Julien and Helmken (1978). Its intensity is approximately twice that of the source described here, and its position is ~1.8° away, therefore the two potential sources are apparently not associated.

Although our statistics are limited, the maximum angular size of the X-ray source region may be inferred from the absence of any broadening of the source profile as determined by the scanning data. We estimate that the angular extent of the X-ray emission is less than 1/2° in declination and 1° in right ascension. There are no indications of variability between the two observations six months apart, nor are there any strong indications of variability on a time scale of a day.

In the discussion that follows we make the specific assumption that the X-ray source is associated physically with γ195+5. The location of the source then rules out the possibility raised by Davies, Fabian, and Pringle (1978) that γ195+5 is γ Geminorum since it is 2° from the best X-ray position (see figure 1). One of the models proposed by Maraschi and Treves (1977) was that of an X-ray pulsator consisting of a binary system containing an

accreting neutron star. The normal X-rays to be expected from such an object were assumed to be shielded up to 10 keV. Our spectrum (figure 2) would appear to eliminate that possibility. Other models of Maraschi and Treves based on an interpretation of the 59 s period as the free precession of a rapid (i.e. young) pulsar are not ruled out by the X-ray flux we observe. In the picture presented by Abdulwahab and Morrison (1978) γ195+5 is assumed to be an interstellar cloud 2^{o} in angular extent in which cosmic rays from the Crab supernova event are interacting. The approximate limit we place on the angular size of the X-ray emitting region of ~1/2 square degree would increase the needed gas density within the cloud by a factor of 15 at least, assuming the line-of-sight dimension of the cloud shrinks proportionately. However this does not appear to present a problem for this particular model. Unfortunately the level of X-ray emission to be expected from cosmic ray interactions in the cloud is uncertain because of the lack of observational data on the sub MeV component of cosmic ray electrons.

We can make the following comparison of the X-ray spectrum given in figure 2 with the γ-ray point. The X-ray spectrum appears to be too steep to extrapolate simply to the γ-ray region. The best power law extrapolates to $\sim 10^{-4}$ of the γ-ray flux value. Therefore, a single mechanism interpretation of both the X-ray and γ-ray data, such as for example synchrotron emission, may be inappropriate. The level of hard X-rays and low energy γ-rays suggested by the figure are discouraging to experimenters who may attempt their detection. For example, at 100 keV the energy flux density that one may guess from the figure is $\sim 10^{-4}$ keV/cm^2-s-keV, less than 1/100

of the total emission from the Crab at this energy. It is interesting to note that the luminosity per decade of the source in the γ-ray region is more than than a factor of 10 greater than it is in the 1-10 keV region.

In summary, we have searched the region of the γ195+5 for X-ray emission to a level of $\sim 10^{-11}$ ergs/ cm^2-s. We have detected one source whose position is in agreement with the position of the γ-ray source. The area of the X-ray box is approximately 5 times smaller than the estimated γ-ray error region and will guide further observations at X-ray and other wavelengths. The probability that the source is located by chance within the γ-ray error region is estimated to be 9%. The X-ray spectrum appears too steep to extrapolate simply toward the 100 MeV point.

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FIGURE CAPTIONS

Figure 1: 90% confidence error box for the X-ray source and the SAS-2 (Thompson et al. 1977a) error box for γ195+5 and the COS-B (Hermsen et al. 1977) error box for CG195+4. Also shown is the position of γ Geminorum.

Figure 2: The energy flux density, E dN/dE, of the X-ray source. The photon number spectrum may be fitted either with a power law $dN/dE \propto E^{-\alpha}$ with $\alpha = 2.6^{+0.7}_{-0.6}$ and absorption column density $< 7\times10^{22}$ H atoms cm^{-2} or by thermal bremsstrahlung emission with $kT = 6 \pm 3$ keV and absorption $< 4 \times 10^{22}$ H atoms cm^{-2}. The cross-hatched region indicates a range of permissible spectra consistent with the errors on the 2-10 keV flux. Some spectra which lie inside the cross-hatched region are unlikely by virtue of the error limits on the absorption, the power law exponent, or the temperature. Also shown is the γ-ray energy flux (Thompson et al. 1977a) assuming a number spectral index, α, in the vicinity of 100 MeV of 1.5.

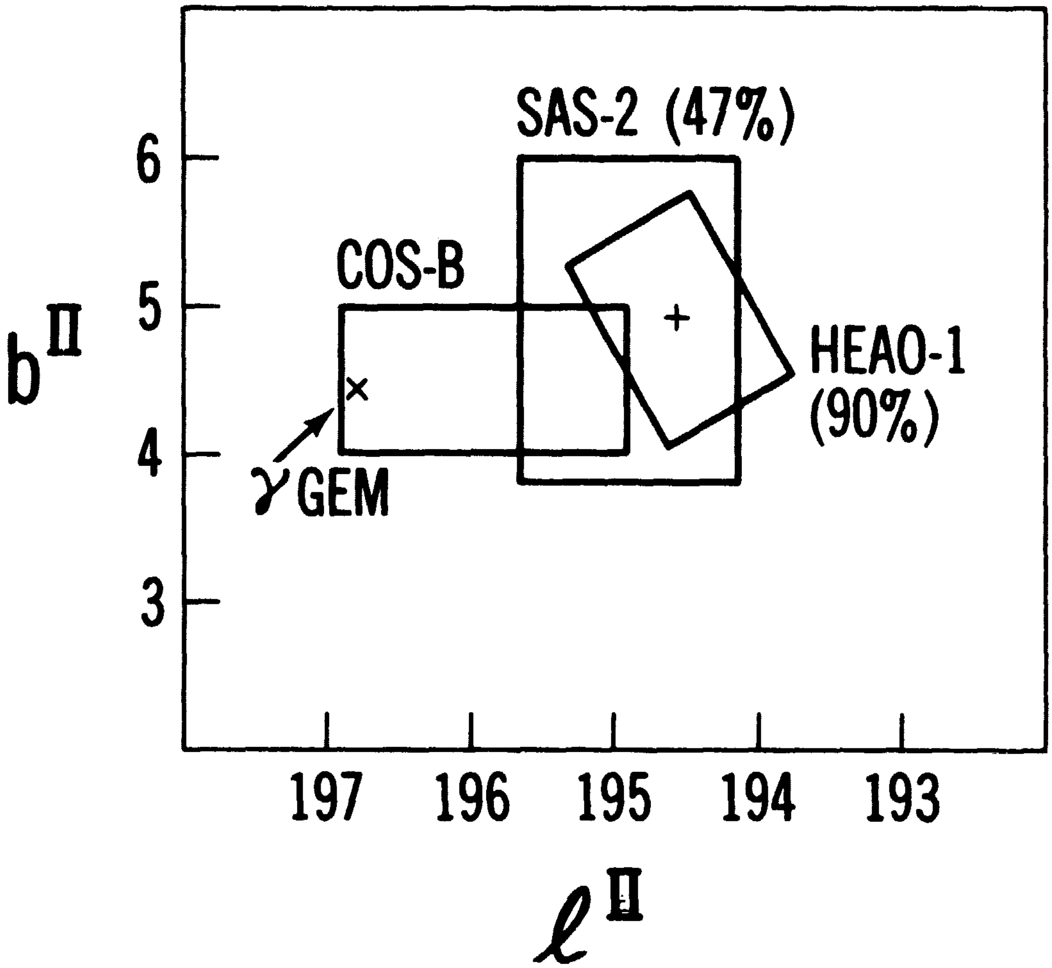
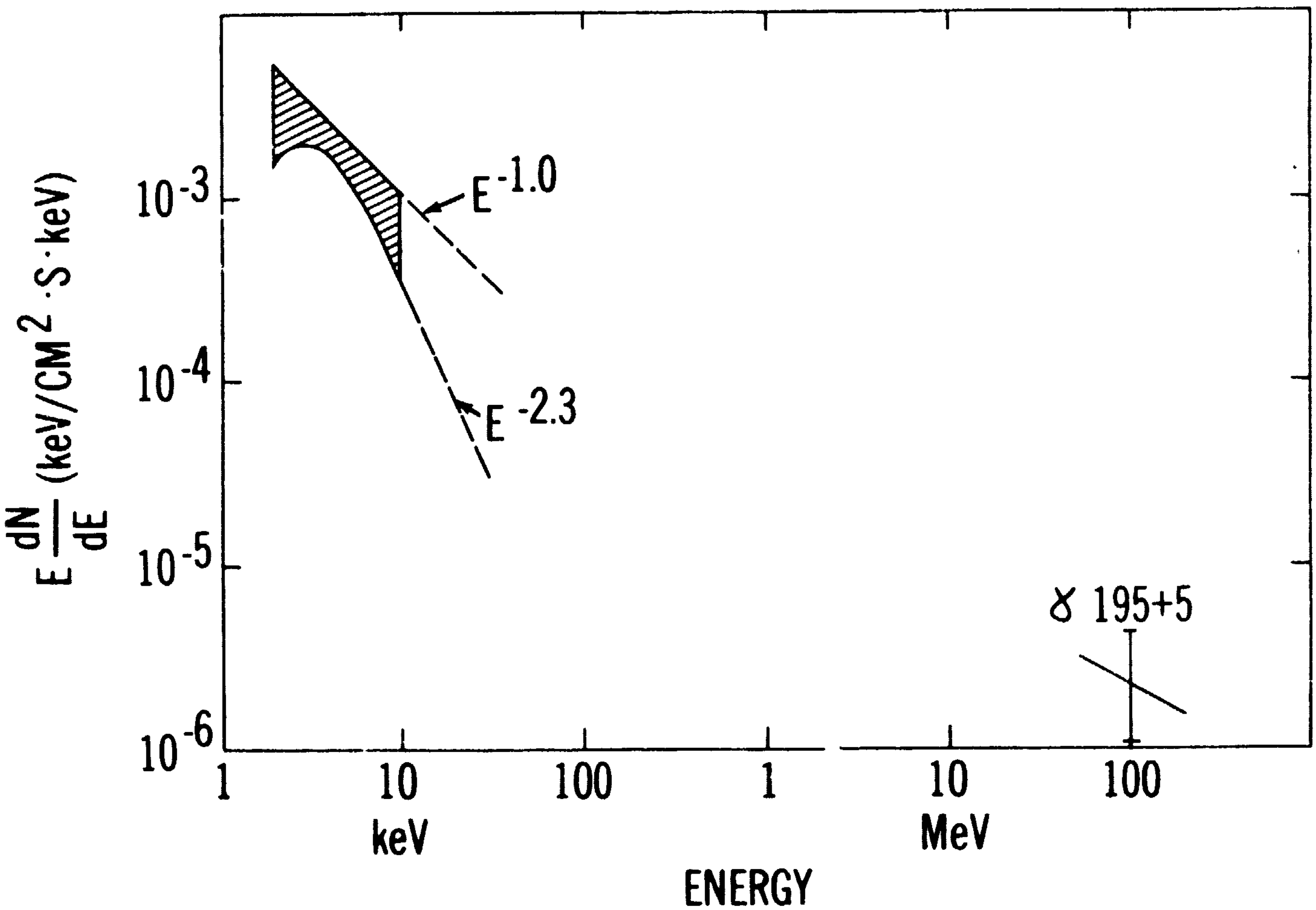


Figure 1



$E\frac{dN}{dE}$ (keV/CM^2·S·keV)
10^{-3}
10^{-4}
10^{-5}
10^{-6}
$E^{-1.0}$
$E^{-2.3}$
γ 195+5
1
10
100
keV
1
10
100
MeV
ENERGY

Figure 2